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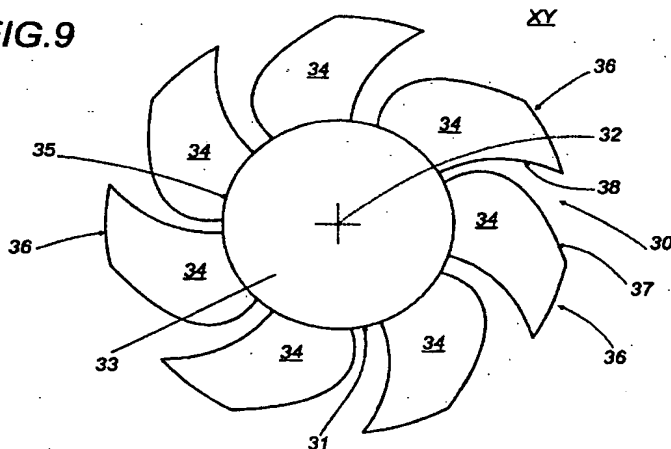
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### (54) Axial flow fan

(57) The axial flow fan (1; 30) comprises a central hub (3; 33) a plurality of blades (4; 34) which have a root (5; 35), and an end (6; 36). According to one embodiment, the blades (4; 34) are spaced at unequal angles ( $\theta_{i, \dots, n}$ ) which can vary in percentage (%) from 0.5% to 10%, compared to the configuration with equal spacing angles ( $\theta_e$ ) for fans with an equal number of blades.

Preferably, the blades (4; 34) are delimited by a convex edge (7; 37), whose projection onto the rotation plane of the fan is defined by a parabolic segment and a concave edge (8; 38) whose projection onto the rotation plane of the fan is defined by a circular arc.

FIG.9



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## Description

[0001] The present invention relates to an axial flow fan for moving air through a heat exchanger and is preferably for use in the cooling and heating systems of motor vehicles.

[0002] Fans of this type must meet certain requirements, among which: low noise level, high efficiency, compact dimensions and ability to obtain good values of pressure head and delivery.

[0003] Patent EP - 0 553 598 B in the name of the same Applicant as the present, discloses a fan with blades having equal spacing angles. The blades have a constant chord length along their entire length and they are delimited at the leading and trailing edges by two curves which, when projected onto the plane of rotation of the fan wheel, are two circular arcs.

[0004] Fans made in accordance with this patent achieve good results in terms of efficiency and low sound pressure, however, the sound distribution of the noise may be irritating to the human ear.

[0005] In fact, with the blades spaced at equal angles, there are cases of resonance with a main harmonic whose frequency is the product of the number of revolutions per second of the fan wheel multiplied by the number of blades.

This resonance gives rise to a hissing noise which may be irritating to the human ear.

[0006] Even if the perception of irritation caused by a sound is mainly subjective, there are basically two reasons which influence the noise disturbance: the degree of sound pressure, that is, the intensity of the noise and how it is distributed in terms of tone. As a result, low intensity noises can also become irritating if the tone distribution of the noise distinguishes it from background noises.

[0007] To solve this problem, fans with blades spaced at unequal angles have been made.

[0008] Calculating an average of the sound intensity values at various frequencies, with the blades spaced at unequal angles the noise produced is almost equal to that with the blades spaced at equal angles. However, the different tone distribution of the noise allows an improvement in the acoustic comfort. However, the fans with the blades spaced at unequal angles have a number of disadvantages.

[0009] The first disadvantage is the fact that in many cases the efficiency of the fans with blades spaced at unequal angles is less than that of the fans with spaced blades of equal angles.

[0010] Another disadvantage is the fact that the fan wheel with blades spaced at unequal angles may be unbalanced.

[0011] The aim of the present invention is to provide an improved axial fan with a very low noise level.

[0012] Another aim of the present invention is to provide an improved axial fan with good efficiency, head and delivery values.

[0013] Yet another aim of the present invention is to provide an improved axial fan whose fan wheel is substantially balanced naturally.

[0014] In accordance with an aspect of the present invention, an axial fan is disclosed as specified in the independent claim. The dependent claims refer to preferred, advantageous embodiments of the invention.

[0015] The invention will now be described with reference to the accompanying drawings, which illustrate preferred embodiments of it, without restricting the scope of the inventive concept, and in which:

- Figure 1 shows a front view of an embodiment disclosed in this invention.
- Figure 2 illustrates in a front view the geometrical features of a blade in some of the embodiments of the fan disclosed by the present invention;
- Figure 3 shows sections of a fan blade in some of the embodiments of this invention taken at regular intervals starting from the hub to the end of the blade;
- Figure 4 illustrates in a perspective view other geometrical features of a blade of some of the embodiments of the fan disclosed by this invention;
- Figure 5 shows a scaled-up detail of a part of the wheel and the related duct in some of the embodiments of this invention;
- Figure 6 is a front view of another embodiment of the present invention;
- Figure 7 shows a diagram representing, in Cartesian co-ordinates, the convex edge of a fan blade in some of the embodiments of the present invention;
- Figure 8 is a diagram showing the changes in the blade angle in different sections of a blade as a function of the radius of the fan in some of the embodiments of this invention;
- Figure 9 is a front view of another embodiment of this invention; and
- Figure 10 shows a schematic front view which defines the spacing angles of the blades in some embodiments of this invention.

[0016] The terms used to describe the fan are defined as follows:

the chord (L) is the length of the straight-line segment subtended by the arc extending from the leading edge to the

trailing edge over an aerodynamic profile of the section of the blade obtained by intersecting the blade with a cylinder whose axis coincides with the axis of rotation of the fan and whose radius  $r$  coincides at a point Q;

the centre line or midchord line (MC) of the blade is the line joining the midpoints of the chords  $L$  to the different rays;

the sweep angle ( $\delta$ ) measured at a given point Q of a characteristic curve of the blade, for example, the curve representing the trailing edge of the fan blade, is the angle made by a ray emanating from the centre of the fan to the point Q concerned and the tangent to the curve at the same point Q;

the skew angle or net angular displacement ( $\alpha$ ) of a characteristic curve of the blade is the angle between the ray passing through the characteristic curve, for example, the curve representing the centre line or the midchord line of the blade, to the fan hub, and the ray passing through the characteristic curve at the end of the blade;

the blade spacing angle ( $\theta$ ) is the angle measured at the centre of rotation between the rays passing through the corresponding points of each blade, for example, an edge at the end of the blades;

the blade angle ( $\beta$ ) is the angle between the plane of rotation of the fan and the straight line joining the leading edge to the trailing edge of the aerodynamic profile of the blade section;

the pitch ratio ( $P/D$ ) is the ratio between the pitch of the helix, that is to say, the amount by which the point Q concerned is axially displaced, that is,  $P = 2 \cdot \pi \cdot r \cdot \tan(\beta)$ , where  $r$  is the length of the ray to the point Q and  $\beta$  is the blade angle at the point Q and the maximum diameter of the fan;

the profile camber ( $f$ ) is the longest straight-line segment perpendicular to the chord  $L$ , measured from the chord  $L$  to the blade camber line; the position of the profile camber  $f$  relative to the chord  $L$  may be expressed as a percentage of the length of the chord itself;

the rake ( $V$ ) is the axial displacement of the blade from the plane of rotation of the fan, including not only the displacement of the entire profile from the plane of rotation but also the axial component due to the blade curvature, if any - also in axial direction.

[0017] With reference to the accompanying drawings, the fan 1 rotates about an axis 2 and comprises a central hub 3 mounting a plurality of blades 4 curved in the plane of rotation XY of the fan 1. The blades 4 have a root 5, an end 6 and are delimited by a convex edge 7 and a concave edge 8.

[0018] Since satisfactory results in terms of efficiency, noise level and head have been obtained by rotating the fan made according to the present invention either in one direction or the other, the convex edge 7 and the concave edge 8 may each be either the leading edge or the trailing edge of the blade. In other words, the fan 1 may rotate in such a way that the air to be moved meets first with the convex edge 7 and then the concave edge 8 or, vice versa, first with the concave edge 8 and then the convex edge 7.

[0019] Obviously, the aerodynamic profile of the blade section must be oriented according to the mode of operation of the fan 1, that is to say, according to whether the air to be moved meets the convex edge 7 or the concave edge 8 first.

[0020] At the end 6 of the blades 4, a reinforcement ring 9 may be fitted. The ring 9 strengthens the set of the blades 4 for example by preventing the angle  $\beta$  of the blade 4 from varying in the area at the end of the blade on account of aerodynamic loads. Moreover, the ring 9, in combination with a duct 10, limits the whirling of the air around the fan and reduces the vortices at the end 6 of the blades 4, these vortices being created, as is known, by the different pressure on the two faces of the blade 4.

[0021] For this purpose, the ring 9 has a thick lip portion 11, that fits into a matching seat 12 made in the duct 10. The distance (a), very small in the axial direction, between the lip 11 and the seat 12 together with the labyrinth shape of the part between the two elements, reduces air whirl at the end of the fan blades.

[0022] Moreover, the special fit between the outer ring 9 and the duct 10 allows the two parts to come into contact with each other while at the same time reducing the axial movements of the fan.

[0023] As a whole, the ring 9 has the shape of a nozzle, that is to say, its inlet section is larger than the section through which the air passes at the end of the blades 4. The larger suction surface keeps air flowing at a constant rate by compensating for flow resistance.

[0024] However, as shown in Figure 6, the fan made according to the present invention need not be equipped with the outer reinforcement ring and the related duct.

[0025] The blade 4, projected onto the plane of rotation XY of the fan 1, has the geometrical characteristics described below.

[0026] The angle at the centre (B), assuming as the centre the geometrical centre of the fan coinciding with the axis of rotation 2 of the fan, corresponding to the width of the blade 4 at the root 5, is calculated using a relation that takes into account the gap that must exist between two adjacent blades 4. In fact, since fans of this kind are made preferably of plastic using injection moulding, the blades in the die should not overlap, otherwise the die used to make the fan has to be very complex and production costs inevitably go up as a result.

[0027] Moreover, it should be remembered that, especially in the case of motor vehicle applications, the fans do not work continuously because a lot of the time that the engine is running, the heat exchangers to which the fans are con-

nedected are cooled by the air flow created by the movement of the vehicle itself. Therefore, air must be allowed to flow through easily even when the fan is not turning. This is achieved by leaving a relatively wide gap between the fan blades. In other words, the fan blades must not form a screen that prevents the cooling effect of the airflow created by vehicle motion. The relation used to calculate the angle (B) in degrees is:

$$B = (360^\circ / \text{No. of blades}) - K; K_{\min} = \mathcal{F} (\text{hub diameter; height of blade profile at the hub}).$$

[0028] The angle (K) is a factor that takes into account the minimum distance that must exist between two adjacent blades to prevent them from overlapping during moulding and is a function of the hub diameter: the larger the hub diameter is, the smaller the angle (K) can be. The value of the angle (K) may also be influenced by the height of the blade profile at the hub.

[0029] The description below, given by way of example only and without restricting the scope of the inventive concept, refers to an embodiment of a fan made in accordance with the present invention. As shown in the accompanying drawings, the fan has seven blades, a hub with a diameter of 140 mm and an outside diameter, corresponding to the diameter of the outer ring 9, of 385 mm.

[0030] The angle (B), corresponding to the width of a blade at the hub, calculated using these values, is  $44^\circ$ .

[0031] The geometry of a blade 4 of the fan 1 will now be described: the blade 4 is first defined as a projection onto the plane of rotation XY of the fan 1 and the projection of the blade 4 onto the plane XY is then transferred into space.

[0032] With reference to the detail shown in Figure 2, the geometrical construction of the blade 4 consists in drawing the bisector 13 of the angle (B) which is in turn delimited by the ray 17 on the left and the ray 16 on the right. A ray 14, rotated in anticlockwise direction by an angle  $A = 3/11 B$  relative to the bisector 13, and a ray 15, also rotated in anticlockwise direction by an angle (A) but relative to the ray 16, are then drawn. The two rays 14, 15 are thus both rotated by an angle  $A = 3/11 B$ , that is,  $A = 12^\circ$ .

[0033] The intersections of the rays 17 and 16 with the hub 3 and the intersections of the rays 14 and 15 with the outer ring 9 of the fan (or with a circle equal in diameter to the outer ring 9), determine four points (M, N, S, T) lying in the plane XY, which define the projection of the blade 4 of the fan 1. The projection of the convex edge 7 is also defined, at the hub, by a first tangent 21 inclined by an angle  $C = 3/4 A$ , that is,  $C = 9^\circ$ , relative to the ray 17 passing through the point (M) at the hub 3.

[0034] As can be seen in Figure 2, the angle (C) is measured in a clockwise direction relative to the ray 17 and therefore the first tangent 21 is ahead of the ray 17 when the convex edge 7 is the first to meet the air flow, or behind the ray 17 when the convex edge 7 is the last to meet the air flow, that is, when the edge 8 is the first to meet the air flow.

[0035] At the outer ring 9, the convex edge 7 is also defined by a second tangent 22 which is inclined by an angle (W) equal to 6 times the angle (A), that is,  $72^\circ$ , relative to the ray 14 passing through the point (N) at the outer ring 9. As shown in Figure 2, the angle (W) is measured in an anticlockwise direction relative to the ray 14 and therefore the second tangent 22 is ahead when the convex edge 7 is the first to meet the air flow, or behind the ray 14 when the convex edge 7 is the last to meet the air flow, that is, when the edge 8 is the first to meet the air flow.

[0036] In practice, the projection of the convex edge 7 is tangent to the first tangent 21 and to the second tangent 22 and is characterised by a curve with a single convex portion, without points of inflection. The curve which defines the projection of the convex edge 7 is a parabola of the type:

$$y = ax^2 + bx + c.$$

[0037] In the embodiment illustrated, the parabola is defined by the following equation:

$$y = 0.013 x^2 - 2.7 x + 95.7.$$

[0038] This equation determines the curve illustrated in the Cartesian diagram, shown in Figure 7, as a function of the related x and y variables of the plane XY.

[0039] Looking at Figure 2 again, the endpoints of the parabola are defined by the tangents 21 and 22 at the points (M) and (N) and the zone of maximum convexity is that nearest the hub 3.

[0040] Experiments have shown that the convex edge 7, with its parabolic projection onto the plane of rotation XY of the fan, provides excellent efficiency and noise characteristics.

[0041] As regards the projection of the concave edge 8 of the blade 4 onto the plane XY, any second-degree curve arranged in such a way as to define a concavity can be used. For example, the projection of the concave edge 8 may

be defined by a parabola similar to that of the convex edge 7 and arranged in substantially the same way.

[0042] In a preferred embodiment, the curve defining the projection of the concave edge 8 onto the plane XY is a circular arc whose radius ( $R_{cu}$ ) is equal to the radius (R) of the hub and, in the practical application described here, the value of this radius is 70 mm.

[0043] As shown in Figure 2, the projection of the concave edge 8 is delimited by the points (S) and (T) and is a circular arc whose radius is equal to the radius of the hub. The projection of the concave edge 8 is thus completely defined in geometrical terms.

[0044] Figure 3 shows eleven profiles 18 representing eleven sections of the blade 4 made at regular intervals from left to right, that is, from the hub 3 to the outer edge 6 of the blade 4. The profiles 18 have some characteristics in common but are all geometrically different in order to be able to adapt to the aerodynamic conditions which are substantially a function of the position of the profiles in the radial direction. The characteristics common to all the blade profiles are particularly suitable for achieving high efficiency and head and low noise.

[0045] The first profiles on the left are more arched and have a larger blade angle ( $\beta$ ) because, being closer to the hub, their linear velocity is less than that of the outer profiles.

[0046] The profiles 18 have a face 18a comprising an initial straight-line segment. This straight-line segment is designed to allow the airflow to enter smoothly, preventing the blade from "beating" the air which would interrupt smooth airflow and thus increase noise and reduce efficiency. In Figure 3, this straight-line segment is labelled (t) and its length is from 14% to 17% of the length of the chord (L).

[0047] The remainder of the face 18a is substantially made up of circular arcs. Passing from the profiles close to the hub towards those at the end of the blade, the circular arcs making up the face 18a become larger and larger in radius, that is to say, the profile camber (f) of the blade 4 decreases.

[0048] With respect to the chord (L), the profile camber (f) is located at a point, labelled (1f) in Figure 3, between 35% and 47% of the total length of the chord (L). This length must be measured from the edge of the profile that meets the air first.

[0049] The back 18b of the blade is defined by a curve such that the maximum thickness ( $G_{max}$ ) of the profile is located in a zone between 15% and 25% of the total length of the blade chord and preferably at 20% of the length of the chord (L). In this case too, this length must be measured from the edge of the profile that meets the air first.

[0050] Moving from the profiles closer to the hub where the maximum thickness ( $G_{max}$ ) has its highest value, the thickness of the profile 18 decreases at a constant rate towards the profiles at the end of the blade where it is reduced by about a quarter of its value. The maximum thickness ( $G_{max}$ ) decreases according to substantially linear variation as a function of the fan radius. The profiles 18 of the sections of the blade 4 at the outermost portion of the fan 1 have the lowest ( $G_{max}$ ) thickness value because their aerodynamic characteristics must make them suitable for higher speeds. In this way, the profile is optimised for the linear velocity of the blade section, this velocity obviously increasing with the increase in the fan radius.

[0051] The length of the chord (L) of the profiles (18) also varies as a function of the radius.

[0052] The chord length (L) reaches its highest value in the middle of the blade 4 and decreases towards the end 6 of the blade so as to reduce the aerodynamic load on the outermost portion of the fan blade and also to facilitate the passage of the air when the fan is not operating, as stated above.

[0053] The blade angle ( $\beta$ ) also varies as a function of the fan radius. In particular, the blade angle ( $\beta$ ) decreases according to a quasi-linear law.

[0054] The law of variation of the blade angle ( $\beta$ ) can be chosen according to the aerodynamic load required on the outermost portion of the fan blade.

[0055] In a preferred embodiment, the variation of the blade angle ( $\beta$ ) as a function of the fan radius (r) follows a cubic law defined by the equation

$$(\beta) = -7 \cdot 10^{-6} \cdot r^3 + 0.0037 \cdot r^2 - 0.7602 r + 67.64$$

The law of variation of ( $\beta$ ) as a function of the fan radius (r) is represented in the diagram shown in Figure 8.

[0056] Figure 4 shows how the projection of the blade 4 in the plane XY is transferred into space. The blade 4 has a rake V relative to the plane of rotation of the fan 1.

[0057] Figure 4 shows the segments joining the points (M', N') and (S', T') of a blade (4).

[0058] These points (M', N', S', T') are obtained by starting from the points (M, N, S, T) which lie in the plane XY and drawing perpendicular segments (M, M'), (N, N'), (S, S'), (T, T') which thus determine a rake (V) or, in other words, a displacement of the blade 4 in axial direction. Moreover, in the preferred embodiment, each blade 4 has a shape defined by the arcs 19 and 20 in Figure 4. These arcs 19 and 20 are circular arcs whose curvature is calculated as a function of the length of the straight-line segments (M', N') and (S', T'). As shown in Figure 4, the arcs 19 and 20 are offset from the corresponding straight-line segments (M', N') and (S', T') by lengths (h1) and (h2) respectively. These lengths (h1) and (h2) are measured on the perpendicular to the plane of rotation XY of the fan 1 and are calculated as a percentage

of the length of the segments (M', N') and (S', T') themselves.

[0059] The dashed lines in Figure 4 are the curves - parabolic segment and circular arc - related to the convex edge 7 and to the concave edge 8

[0060] The rake V of the blade 4, both as regards its axial displacement component and as regards curvature makes it possible to correct blade flexures due to aerodynamic load and to balance the aerodynamic moments on the blade in such a way as to obtain uniform axial air flow distributed over the entire front surface of the fan.

[0061] All the characteristic values of the fan blade, according to the embodiment described, are summarised in the table below where r is the generic fan radius and the following geometrical variables refer to the corresponding radius value:

L indicates the chord length;

f indicates the profile camber

t indicates the initial straight-line segment of the blade section;

1f indicates the position of the profile camber relative to the chord L;

$\beta$  indicates the angle of the blade section profile in sexagesimal degrees;

x and y indicate the Cartesian co-ordinates in the plane XY of the parabolic edge of the blade.

r	70	100.6	131.2	161.9	179
L	59.8	68.7	78.2	73	71.2
f	8.2	7.5	7.8	6.7	5
t	10	10.5	11	10.5	10
1f	21	25.5	31.2	32.8	33
$\beta$	30.1	21.9	15.7	13.3	11.1
x	65.3	93.2	126.1	161.9	176.4
y	-25.2	-43.0	-38.1	-0.7	23.9

[0062] Experiments comparing the conventional fans with those made in accordance with the embodiments using blades spaced at an equal angle  $\theta$ , show that there is a decrease in the sound power of about 25% to 30%, measured in dB(A) with an improvement in acoustic comfort.

[0063] Furthermore, under the same conditions of air delivery, the fans made according to the embodiments with blades spaced at an equal angle  $\theta$ , have developed head values up to 50% greater compared to the conventional fans of this type.

[0064] In fans made according to the embodiments, with blades spaced at an equal angle  $\theta$ , passing from a blades back to a blades forward configuration, there are no appreciable changes in noise level. Moreover, under certain working conditions of the fan, in particular in the high head range, the blades forward configuration delivers 20-25% more than the blades back configuration.

[0065] Figures 9 and 10 show another embodiment of a fan 30 comprising a wheel 31 with blades 34 spaced at unequal angles  $\theta$ . The embodiment with blades of unequal angles  $\theta$  further improves the acoustic comfort. The different noise distribution from the fan made in accordance with this embodiment makes it even more pleasant to the human ear.

[0066] With reference to Figures 9 and 10, the wheel 31 has seven blades 34 positioned at the following angles, expressed in sexagesimal degrees:

$\theta_1=55.381;$	$\theta_2=47.129;$	$\theta_3=50.727;$	$\theta_4=55.225;$
$\theta_5=50.527;$	$\theta_6=48.729;$	$\theta_7=52.282$	

[0067] If the wheel 31 had the blades 34 spaced at equal angles or as the fans embodied in Figures 1 and 6, the spacing angle would be  $\theta_a=360^\circ/7 = 51.429^\circ$ .

[0068] The table set out below shows the values of the unequal angles  $\theta_1, \dots, \theta_n$  and the absolute and percentage

deviations of the values of the unequal angles  $\theta_{i, \dots, n}$  compared to the corresponding value of the equal angle  $\theta_0$  for fans with seven blades:

number of blades			7	
angles	blades with unequal angles ( $\theta_{i, \dots, n}$ )	blades with equal angles ( $\theta_0$ )	deviations ( $\theta_{i, \dots, n} - \theta_0$ )	deviation % $\frac{(\theta_{i, \dots, n} - \theta_0)}{\theta_0} \cdot 100$
$\theta_1$	55.381	51.429	3.952	7.685
$\theta_2$	47.129	51.429	-4.300	-8.360

$\theta_3$	50.727	51.429	-0.702	-1.364
$\theta_4$	55.225	51.429	3.796	7.382
$\theta_5$	50.527	51.429	-0.902	-1.753
$\theta_6$	48.729	51.429	-2.700	-5.249
$\theta_7$	52.282	51.429	0.853	1.659
TOTAL	360°	360°	0.00	0.00

[0069] More precisely, the second column shows the values of the angles  $\theta_{i, \dots, n}$ , in accordance with the present embodiment; the third column shows the values of the angles  $\theta_0$  when all angles are equal; the fourth column shows the algebraic difference or algebraic deviation between the values of the angles of the second and third column; the fifth column shows the value of the deviation of the fourth column expressed as a percentage of the angles in the third column  $\theta_0$ .

[0070] The table shows that the percentage and algebraic deviation in the angles are relatively low compared to the configuration of blades spaced at equal angles. According to the present embodiment, the values of the percentage deviation of the blade spacing angles should be between 0.5% and 10%.

[0071] Hence, even if an improvement in noise characteristics is achieved, the efficiency of the wheel with the blades spaced at equal angles is substantially the same.

[0072] As can be seen in more detail below, if the deviation percentage values are maintained within these limits, wheels which are substantially balanced can be made even with any number of blades  $n$  greater than three, and therefore different from the wheel 31 which has seven blades as shown in the example. Even the embodiments made with a number of blades 34 other than seven and with those limitations regarding angular spacing achieve good results in terms of efficiency and noise level.

[0073] The noise produced by the fans made with the angles  $\theta_{i, \dots, n}$  mentioned above has almost the same intensity but is less irritating to the human ear. A good result was achieved regarding the pleasantness of the noise in the con-

figuration with the blades forward and the configuration with the blades back. Preferably, the configuration of the blades 34 mentioned above can be used in combination with the blades 4 with a parabolic edge 7 of other embodiments previously mentioned. Also in this case, the values of head, delivery and efficiency are substantially invariable.

[0074] Another advantage of this configuration is that the centre of gravity is always on the rotation axis 32 of the fan 30. In analytical terms considering a reference system whose origin is on the rotation axis, the following is true:

$$X_g = \frac{\sum m_i \cdot x_i}{\sum m_i} = 0 ;$$

$$Y_g = \frac{\sum m_i \cdot y_i}{\sum m_i} = 0 .$$

where the  $X_g$  and  $Y_g$  are the Cartesian coordinates of the centre of gravity of the fan wheel 30 and  $m_i x_i y_i$  are the mass and the Cartesian co-ordinates of the centre of gravity of each blade 34, respectively.

[0075] In the example, shown in figures 9 and 10 of a wheel 31 with  $n$  blades of equal mass  $m$  the formula is the following:

$$X_g = \frac{\sum m \cdot x_i}{m \cdot n} = 0 ;$$

$$Y_g = \frac{\sum m \cdot y_i}{m \cdot n} = 0 .$$

With this configuration a wheel 31 already substantially balanced without the need to intervene on the mass of the blades 34 can be achieved, or any such an intervention is reduced to the minimum compared to that needed to balance the wheels of the type with have blades spaced at unequal angles. There are therefore advantages in terms of simple and economical construction.

## Claims

1. An axial flow fan (1; 30) rotating in a plane (XY) and comprising a central hub (3; 33), a plurality ( $n$ ) greater than three of blades (4; 34), each blade having a root (5; 35), and an end (6; 36), the blades (4; 34) being also delimited by a first edge (7; 37) and a second edge (8; 38), and consisting of sections with aerodynamic profiles (18) with a blade angle ( $\beta$ ) which decreases gradually and constantly from the root (5; 35) towards the end (6; 36) of the blade (4; 34), the blades (4; 34) being spaced at unequal angles ( $\theta_{1,...,n}$ ), characterised in that these unequal spacing angles ( $\theta_{1,...,n}$ ) may vary in percentage ( $\theta\%$ ) by values between 0.5% and 10% compared to the configuration with



the equal spacing angles ( $\theta_e$ ) for fans with the same number (n) of blades, that is:  
 $0.5\% \leq \theta_e \leq 10\%$ , where

$$\theta_e = \frac{\theta_{1, \dots, n}}{\theta_e} \cdot 100;$$

so that the fan (30) is substantially balanced naturally.

- 10 2. The fan according to claim 1 characterised in that it comprises seven blades (34) and in that the unequal spacing angles ( $\theta_{1, \dots, n}$ ) of the blades (34) have the following values, expressed in sexagesimal degrees:

15	$\theta_1=55.381;$	$\theta_2=47.129;$	$\theta_3=50.727;$	$\theta_4=55.225;$
	$\theta_5=50.527;$	$\theta_6=48.729;$	$\theta_7=52.282.$	

- 20 3. The fan according to claim 1 or 2 characterised in that the projection of the convex edge (7) onto the plane (XY) is defined by a parabolic segment.
4. The fan according to any of the previous claims characterised in that the projection of the concave edge (8) onto the plane (XY) is defined by a second degree geometric curve.
- 25 5. The fan according to any of the previous claims characterised in that the projection of the concave edge (8) onto the plane (XY) is defined by a parabolic segment.
6. The fan according to claim 4 characterised in that the projection of the concave edge (8) onto the plane (XY) is defined by a circular arc.
- 30 7. The fan according to any of the previous claims characterised in that the aerodynamic profiles (18) have a face (18a) comprising at least one straight-line segment (t).
8. The fan according to claim 7 characterised in that the aerodynamic profiles (18) have a face (18a) comprising a segment, following the initial segment (t), that is substantially made up of circular arcs.
- 35 9. The fan according to claim 7 or 8 characterised in that the aerodynamic profiles (18) have a chord length (L) and a back (18b) defined by a convex curve which, in combination with the face (18a), determines a maximum thickness value ( $G_{max}$ ) of the profile in a zone between 15% and 25% of the total length of the chord (L) measured from the edge that meets the air first.
- 40 10. The fan according to any of the previous claims characterised in that each blade (4) projected onto the plane (XY) is delimited by four points (M, N, S, T), lying in the plane (XY) and defined as a function of an angle (B) relative to the width of a single blade (4) subtended at the centre of the fan; and being characterised also in that the four points (M, N, S, T) are determined by the following characteristics:
- 45

the points (M) and (S) are located at the hub (3) or at the root (5) of the blade (4) and are defined by the rays (16, 17) emanating from the centre of the fan and forming the angle (B);

the point (N) is located at the end (6) of the blade (4) and is displaced in anticlockwise direction by an angle (A) =  $3/11(B)$  relative to the bisector (13) of the angle (B);

the point (T) is located at the end (6) of the blade (4) and is displaced in anticlockwise direction by an angle (A) =  $3/11(B)$  relative to the ray emanating from the centre of the fan and passing through the point (S).

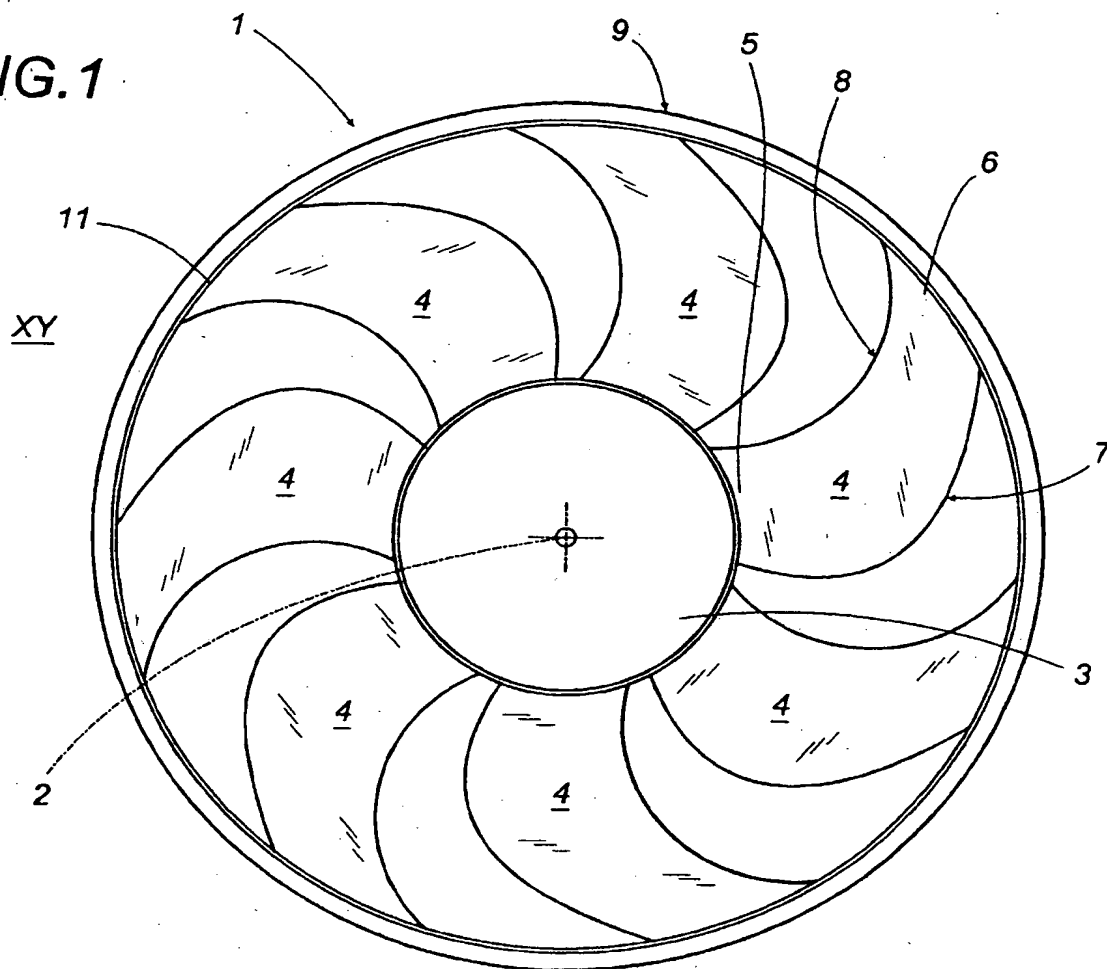
- 55 11. The fan according to claim 10, characterised in that the projection of the convex edge (7) onto the plane (XY) at the point (M) has a first tangent (21) inclined by an angle (C) equal to three quarters of (A) relative to a ray (17) passing through the point (M); and characterised also in that the projection of the convex edge (7) onto the plane (XY) at the point (N) has a second tangent inclined by an angle (W) equal to six times (A) relative to a ray (14) passing through the point (N); the first and second tangents (21, 22) being ahead of the corresponding rays (17, 14) when

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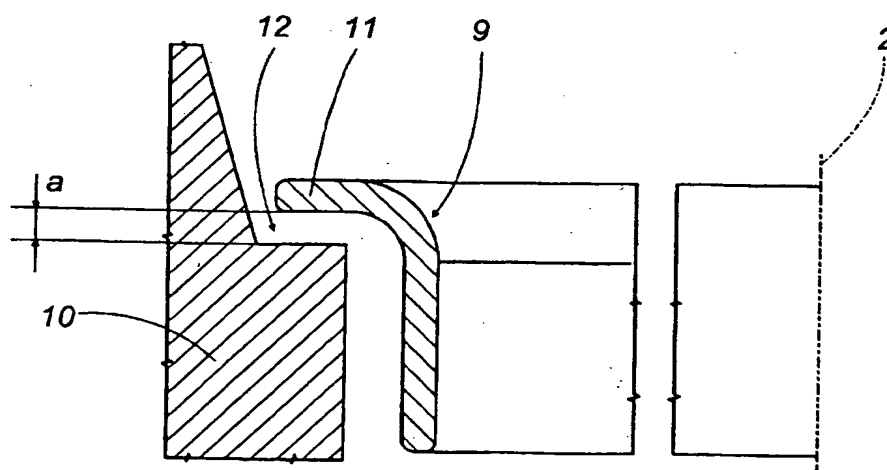
the direction of rotation of the fan (1) is such that the convex edge (7) is the first to meet the air flow and the first and second tangents (21, 22) are arranged in such a way as to define a curve in the plane (XY) that has a single convex portion without points of inflection.

- 5 12. The fan according to any of the previous claims from 6 to 11 characterised in that the circular arc formed by the projection of the concave edge (8) onto the plane (XY) has a radius ( $R_{cu}$ ) equal to the radius (R) of the hub (3).
- 10 13. The fan according to any of the previous claims characterised in that the blades (4) are formed of sections whose aerodynamic profiles (18) have a blade angle ( $\beta$ ) that decreases gradually and constantly from the root (5) towards the end (6) of the blade (4) according to a cubic law of variation as a function of the radius.

**FIG. 1**



**FIG.5**



**FIG.2**

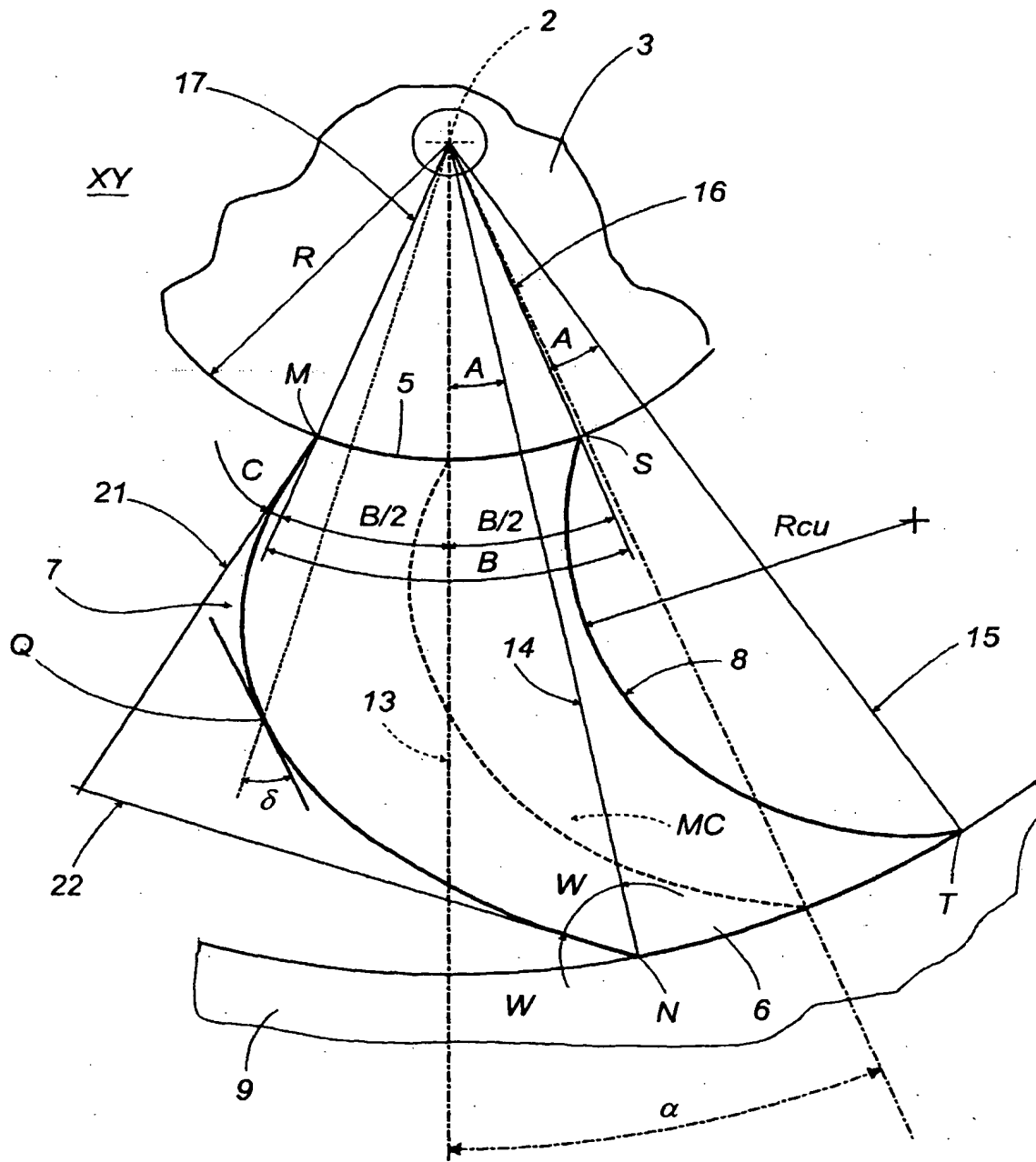


FIG.3

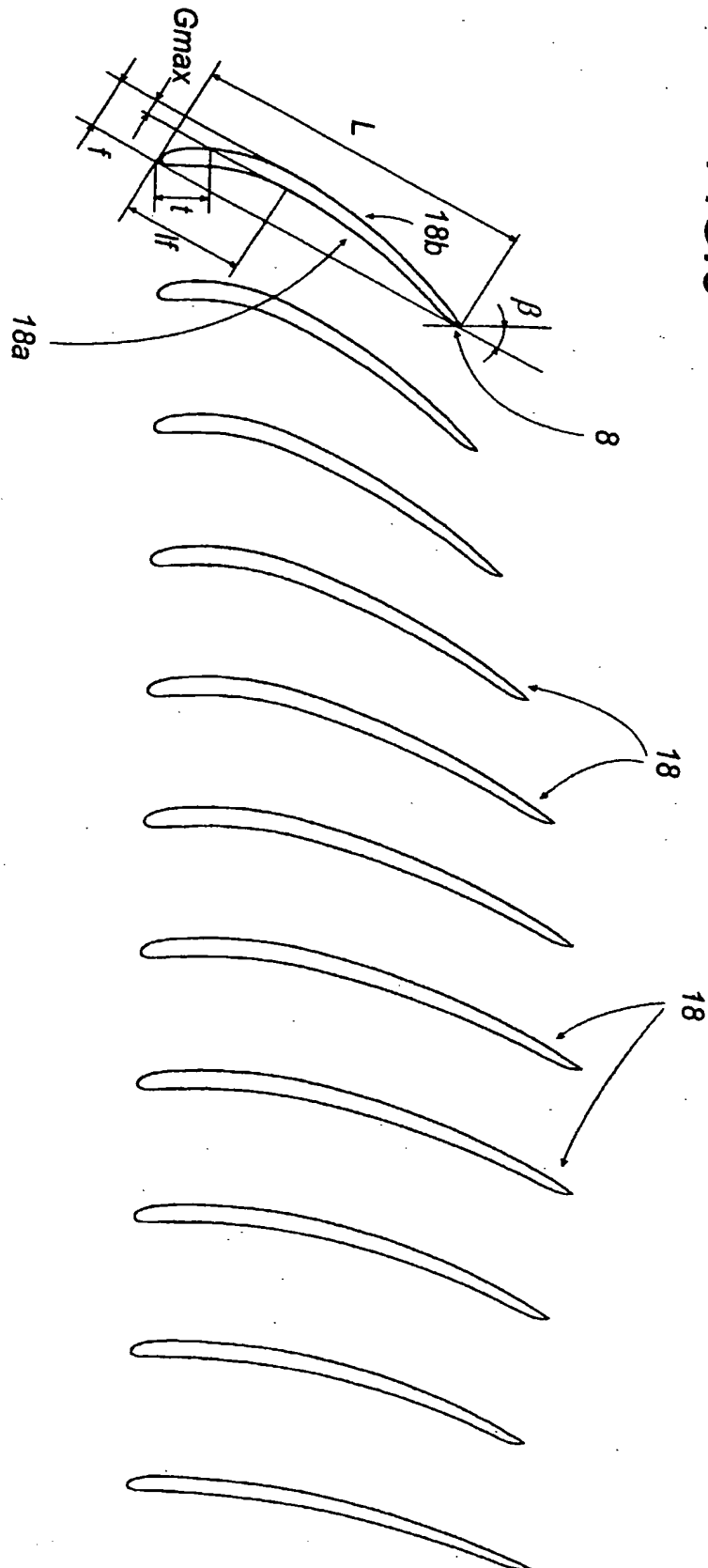


FIG.4

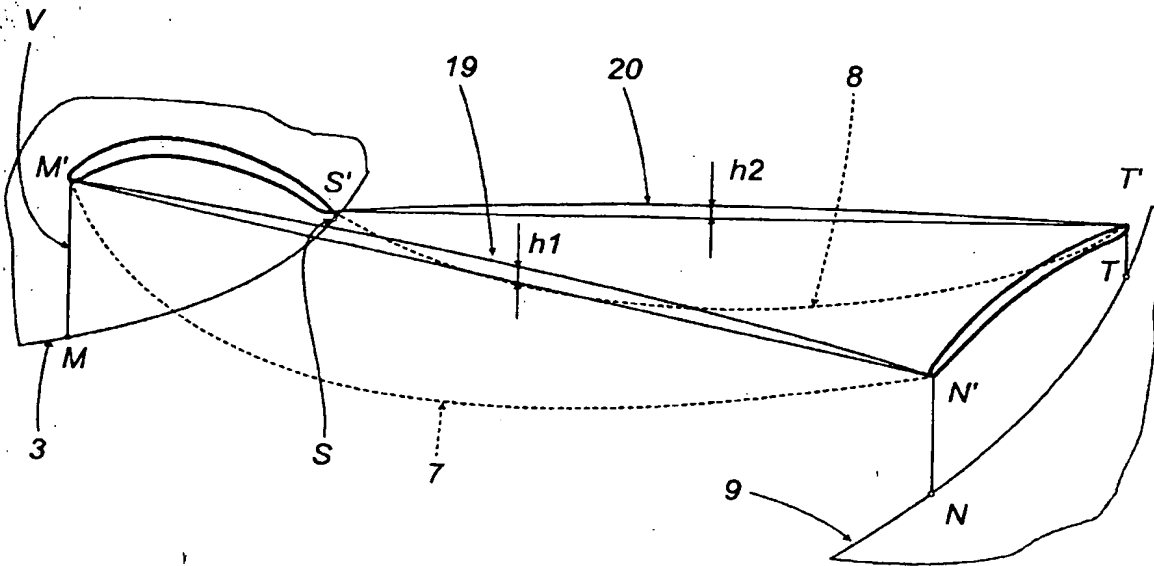


FIG.6

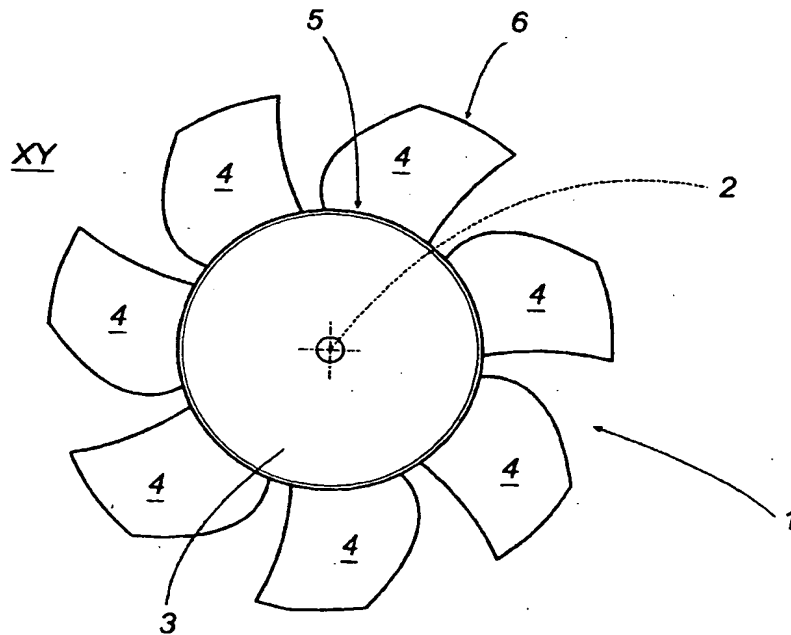


FIG. 7

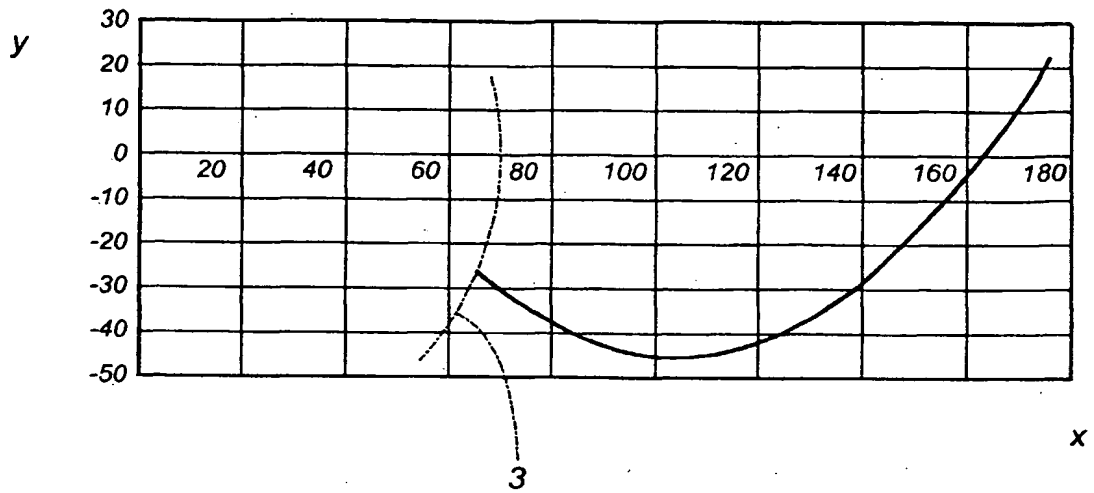


FIG. 8

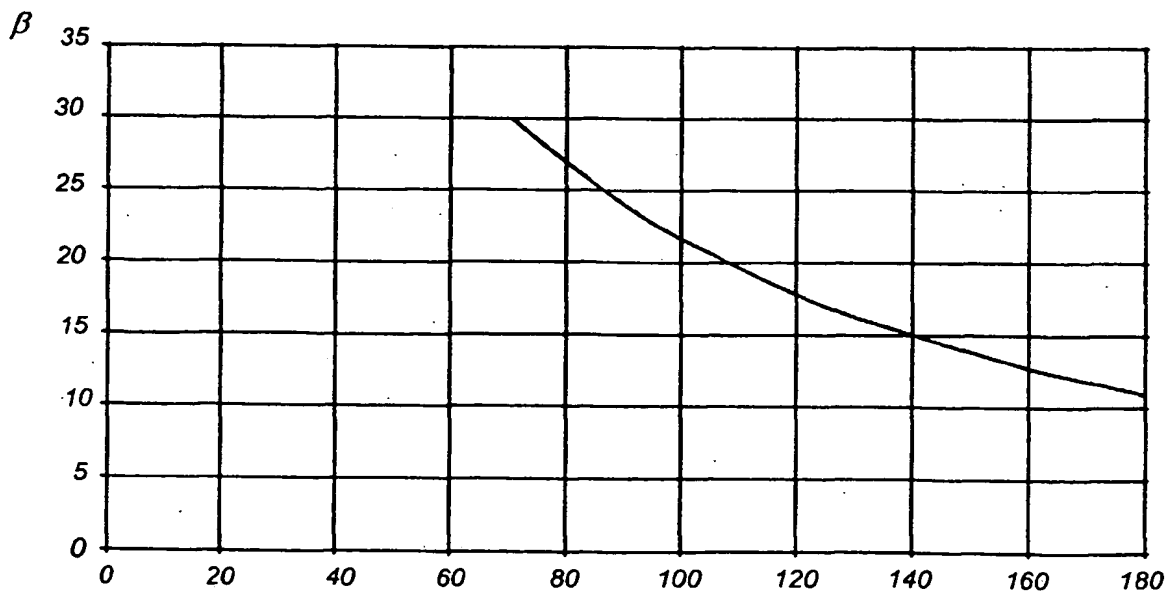


FIG.9

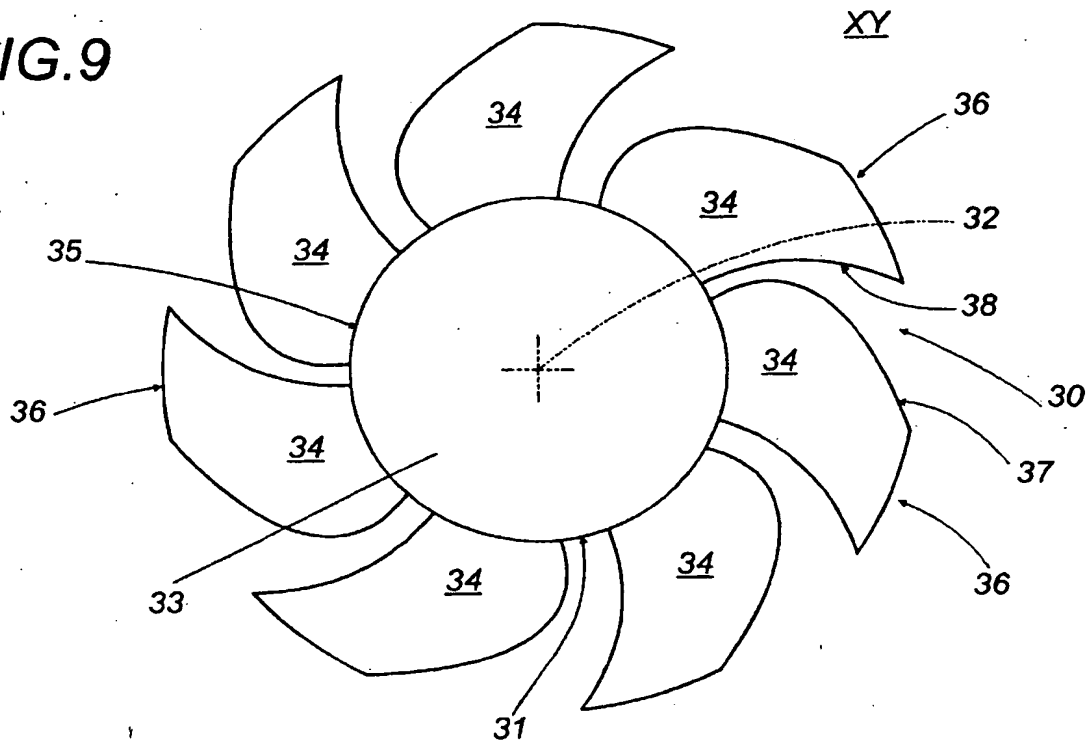
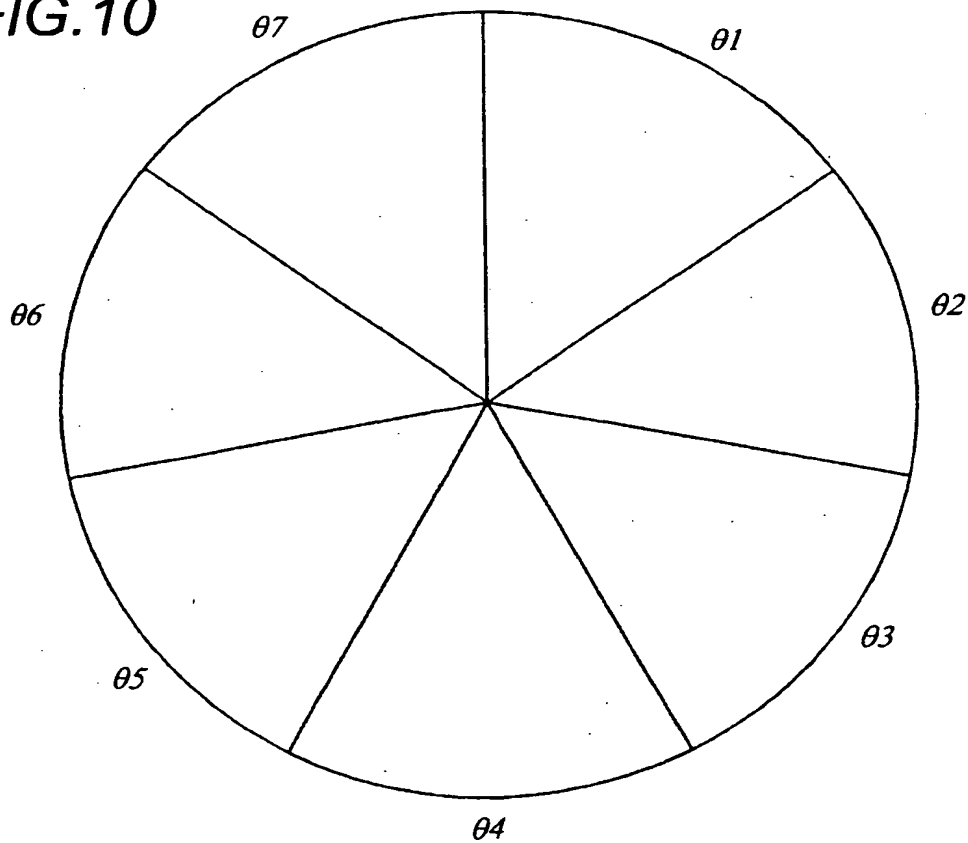


FIG.10







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# EUROPEAN SEARCH REPORT

Application Number  
EP 98 12 4401

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 2 121 484 A (GEN DYNAMICS CORP) 21 December 1983 * page 4, line 25 - line 53 *	1	F04D29/32 F04D29/66 F04D29/38
A	WO 91 02165 A (AIRFLOW RES & MFG) 21 February 1991 * page 5, line 13 - line 15; figure 1 *	1	
A	US 4 253 800 A (SEGAWA YORIHIDE ET AL) 3 March 1981 * page 2, line 49 - line 55 * * column 3, line 16 - line 60; figures 5,7 *	1	
A	GB 957 393 A (CONTINENTAL MOTORS CORPORATION) 6 May 1964 * the whole document *	1	
A	DE 37 16 326 A (SCHEMP HIRTH GMBH & CO KG) 1 December 1988 * column 3, line 21 - line 64; figures 1,2 *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			F04D
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 16 June 1999	Examiner Teerling, J
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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16-06-1999

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
GB 2121484	A	21-12-1983	US 4474534 A	02-10-1984
			CA 1223577 A	30-06-1987
WO 9102165	A	21-02-1991	US 5000660 A	19-03-1991
			DE 69022730 D	02-11-1995
			DE 69022730 T	18-04-1996
			EP 0487563 A	03-06-1992
			ES 2078975 T	01-01-1996
			US 5415780 A	16-05-1995
US 4253800	A	03-03-1981	JP 55025555 A	23-02-1980
GB 957393	A		NONE	
DE 3716326	A	01-12-1988	NONE	

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